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Pulsar Observations with the GMRT

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Abstract. The Giant Meter-wave Radio Telescope (GMRT) being built by the National Centre for Radio Astrophysics of TIFR near Pune will become one of the most sensitive instruments for pulsar research. In this paper, we describe briefly the planned pulsar observations with the GMRT. We also discuss in some detail the design of instrumentation being built by RRI and NCRA for this purpose.

Key words: Pulsars—observations—instrumentation.

1. Introduction

The Giant Meter-wave Radio Telescope (Swarup *et al.* 1991), which is presently under construction, when completed will undoubtedly be one of the most sensitive instruments for search and observations of pulsars. The large effective collecting area (30 dishes of $\sim 1000\,m^2$ area per dish) and sufficiently wide bandwidth (32 MHz) that would be available, needs to be supplemented by suitable back-end instrumentation which takes into account some special requirements for pulsar observations. A major collaborative effort is on between the National Centre for Radio Astrophysics (NCRA), Pune and the Raman Research Institute (RRI), Bangalore, to design and build the required instrumentation and to develop the necessary analysis software for pulsar observations with GMRT.

The observational program envisaged by the staff of NCRA and RRI may be broadly classified as follows: 1) Pulsar Search and 2) Studies of known pulsars. In the following sections we discuss them separately as they require different strategies.

2. Proposed pulsar searches at GMRT

Most of the ~ 600 pulsars known till date have been discovered in major surveys conducted with several single-dish telescope in the world, usually at frequencies near 400 MHz. Majority of the known pulsars lie within 3 kpc from the sun indicating that a large population that lies farther away from us is yet to be discovered and can be revealed only in relatively deeper searches.

The searches proposed with the GMRT are designed to be substantially deeper than most of the major existing surveys and to retain high sensitivity down to millisecond periods even for objects at large distances. The proposed searches include extensive surveys, one in the Galactic plane and another at high galactic latitudes, as well as many targeted searches in the directions of supernova remnants, globular clusters, steep spectrum sources etc..

The parameters in which the search is routinely made in the major existing surveys are confined to direction, period, dispersion measure and duty cycle of the pulse. In the proposed search program, an extra dimension of the acceleration will be included for routine search to retain sensitivity for short period pulsars in relatively tight binary systems.

While conducting large scale surveys one invariably looks for a trade-off between the sensitivity and the speed of a survey. Pulsar search sensitivity depends not only on the effective collecting area, center frequency, total bandwidth, number of polarisation channels and integration time used, but also on the time and frequency resolutions. The speed of a survey on the other hand depends on the integration time per field, the sky area per field and the total sky area to be surveyed. In the case of GMRT, a trade-off between the effective collecting area and the sky area per field is the main consideration. We have considered two possible modes, namely, 'a phased array mode' where the dish outputs are added before detection to have the maximum available collecting area in the direction of the phase center, and 'an incoherent array mode' where detected outputs from the dishes are combined giving an effective collecting area of $\sqrt{N}$ times the area of single dish (for N dishes). In the first mode, however, the field of view will always be much smaller (equal only if the array had been most compact) than $(1/N)$ of that in the later mode. Hence, we plan to use the 'incoherent array mode' for pulsar surveys while for some targeted searches all the 30 dishes of GMRT used in the 'phased array mode' would offer a more attractive possibility.

Then, for example, a GMRT survey at high galactic latitudes ($b_{II} > 15°$) would go ~ 3.5 times deeper in flux density than the on-going Parkes survey (Bailes, in this volume), requiring a total of about 1000 hrs. of observing at 327 MHz (using 512 channels over 32 MHz bandwidth, 250 μsec sampling, 2 polarization channels, and 5-minute integration per field). For searches in the galactic plane, however, observing at 610 and 1420 MHz would be more appropriate.

2.1 *Instrumentation for pulsar search*

This section describes briefly the digital instrumentation being developed for use in the proposed pulsar searches with the GMRT. The complex spectra available from each of the 30 dishes will be combined in two different ways (as discussed above) using an 'Array Combiner' designed to produce 'phased array' and 'incoherent array' outputs (Deshpande 1989). One of these two outputs will be selected and fed to a 'search preprocessor' (see Ramkumar *et al.* 1994, for details on this preprocessor) where the power spectra will be integrated in time and the fluctuations of the spectra around its long-term mean will be output for recording. Fig. 1 shows a schematic of this hardware.

The survey data per field would be typically ~ 1 Gsamples from a 5 minute observation. For real-time speed of processing, 500 MFLOPS of computing power would be necessary. As an inexpensive solution to meet such demanding requirements, we are developing a special purpose pipeline processor which will have fixed functions while offering the required flexibility in the parameters of the function. The data read from a play-back system will pass through a PC where the dispersion gradient will be linearized and output to the pipeline processor. As shown in Fig. 2 the pipeline processor would consist of a memory that would store 1 Gsamples for a given field, followed by an incoherent dedisperser and a long-FFT module. The dedisperser would consist of intelligent memories and adder networks. The dedisperser working at

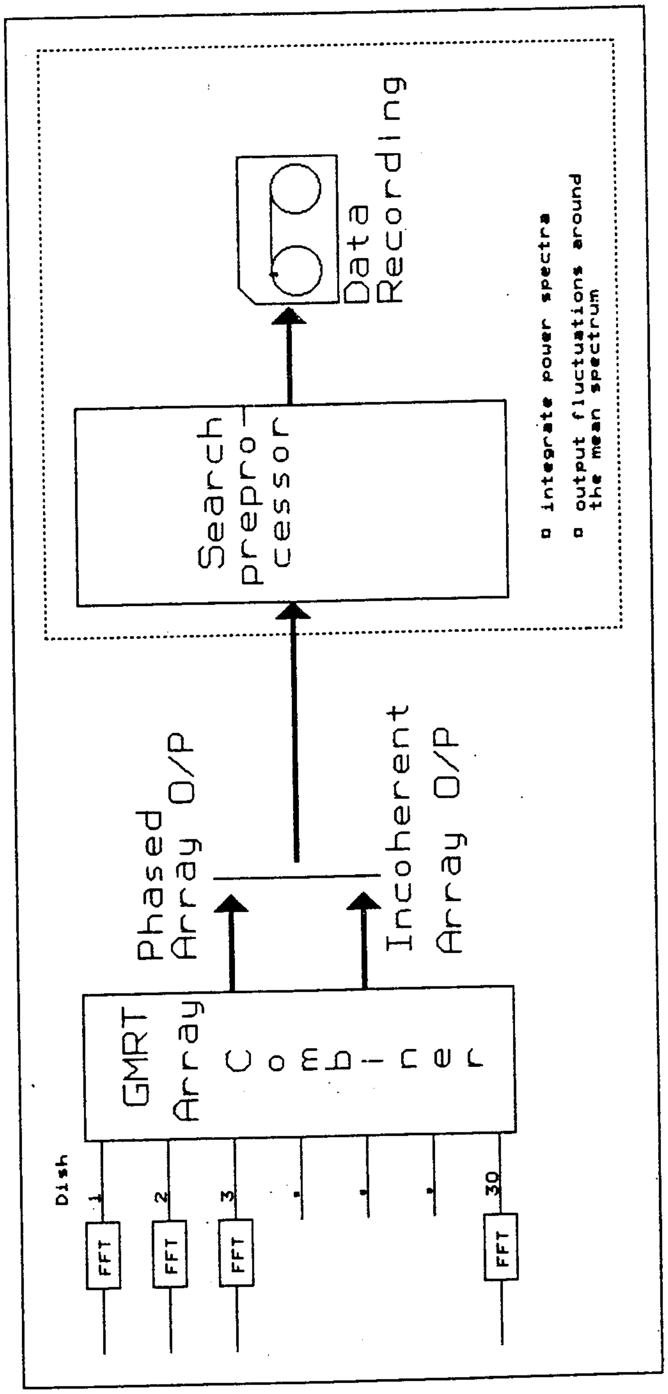

Figure 1. A schematic of the hardware (on-line) for pulsar search.

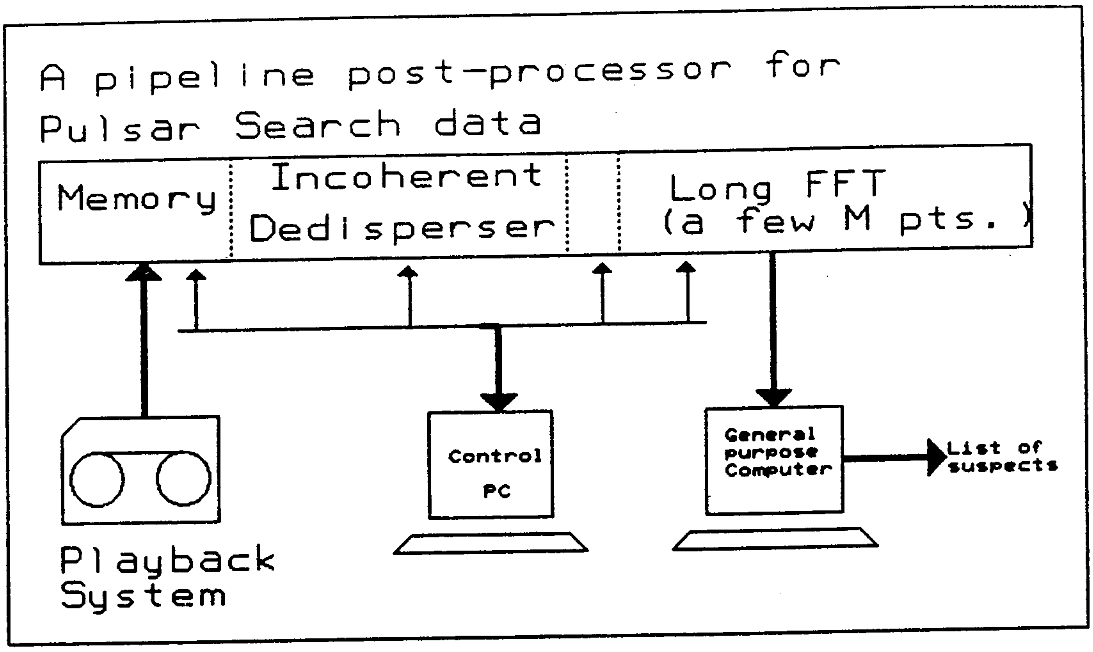

Figure 2. A simplified block diagram of the off-line processor for pulsar search data.

typically 3 MHz throughput rate would produce a (few) Mega-point output, corresponding to each one of (typically) ~ 800 dispersion measures to be searched, every third of a second. An already dedispersed output, will be resampled corresponding to an assumed acceleration and will be Fourier transformed at a fast rate and will be sent to a general-purpose computer having moderate computing capability (~ 30–50 MFLOPS). All the flexibility in harmonic folding, candidate selection etc. can then be achieved through the general-purpose computer.

3. Studies of known pulsars

The possible studies of pulsar can be classified in three main areas of interest, namely: emission mechanism, timing of pulsars, and studies of the intersteller medium using pulsars as probes. Multi-frequency polarimetry with high time-resolution average profiles and single pulse studies including those of microstructure are of importance in the context of pulsar emission mechanism. For pulsar timing, again, high time resolution is a prime consideration while for some studies of ISM where moderate/fine spectral resolution is desirable it is possible to sacrifice time resolution. The trade-off one looks for here is between the resolutions in time & frequency and the sensitivity except when one is interested in microstructure studies.

As the considerations of field of view are unimportant while observing known pulsars, as many of the GMRT dishes as possible can be used in the 'phased array mode' to enhance the sensitivity. At high frequencies, where ionospheric phase errors are expected to be less, it should be possible to use most of the GMRT dishes in this mode.

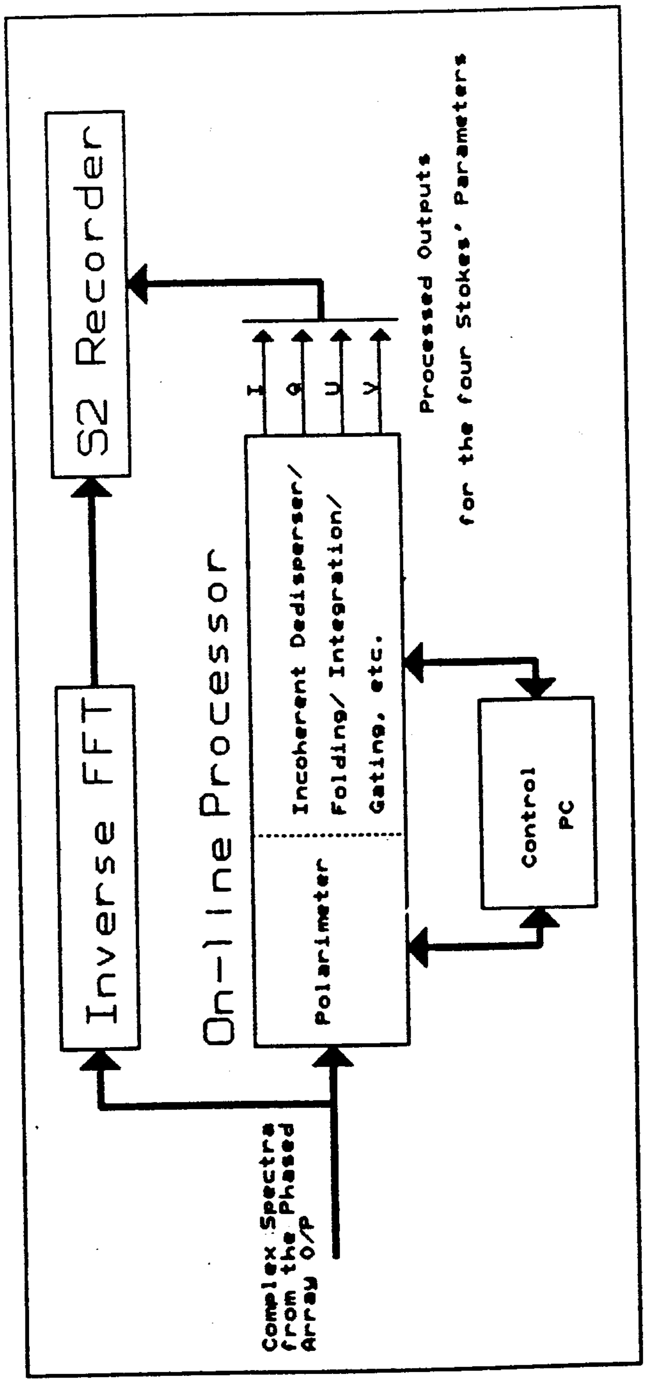

Figure 3. On-line processor for studies of known pulsars.

3.1 *Instrumentation for pulsar observations*

A state-of-art on-line digital processor is being developed to meet the signal processing requirements for most of the above studies. As shown in Fig. 3, the phased array output available from the 'Array Combiner' will be fed to the on-line digital processor. The phased array output can also be saved on to a S2 recorder after transforming the spectra back to time sequences. This provision will be used for off-line coherent dedispersion and also for VLBI experiments between GMRT and the Ooty Radio Telescope (e.g. to measure pulsar proper motions).

The on-line processor is designed to accept 4 complex voltage spectra corresponding to two side bands of 16 MHz for each of the two polarization channels. This processor consists of a full polarimeter (including a provision for corrections for differential Faraday rotation), an incoherent dedisperser, and facilities for smoothing, synchronous averaging, gating etc. The processor will be programmable and flexibly configurable to use various combinations of the processing steps. Due to the use of incoherent dedispersion the time resolution attainable with this processor (at 610 MHz) is at best 16 μs.

An off-line coherent dedisperser is being developed by NCRA to achieve improved time resolutions necessary for microstructure studies and for timing of millisecond pulsars. More details of this system can be found in Izhak *et al.* (1994). With this system the time resolution will be improved to half a microsecond.

4. Progress report

A limited version of the preprocessor for search has been successfully developed and is already in use with the Ooty Radio Telescope for a survey of high galactic latitude pulsars (by NCRA and RRI). A 4-dish 'Array combiner' and a 'search preprocessor' is ready for installation at GMRT. The Array combiner for 30 dishes, the on-line processor (including the polarimeter), the off-line coherent dedisperser and the post-processor for search data are in the pipeline and are expected to be available during 1994.

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